to the cooperative observer. One was in April, 1884, when several buildings were totally wrecked, and the other on June 15, 1896.

Accompanying the tornadoes mentioned in the first several paragraphs the rainfall was quite heavy in some of the central counties, reaching nearly five inches at a few points. Streams were very high, low lands were flooded, and much damage was done to crops by washing. During the same night lightning caused the destruction of barns in several counties, particularly at Cookeville, Putnam County, Loretto, Lawrence County, and Savannah, Hardin County.

The approximate paths of the tornadoes are indicated on the weather map, figure 2, page 255.

CYCLONIC STORM OF JULY 1, 1920, AND ITS EFFECT ON POND ELEVATION AT THE DAM OF THE MISSISSIPPI POWER CO., AT KEOKUK, IOWA.

By R. H. BOLSTER.

[Hydraulic Department, Mississippi River Power Co., Keokuk, Iowa, Sept. 16, 1920.]

On the evening of July 1 Keokuk, Iowa, was visited by probably the worst wind storm in its history. Practically without warning the wind velocity increased from 5 miles per hour at 9:12 p. m. to a velocity of approximately 125 miles per hour at 9:20 or eight minutes later. For three successive periods of about two minutes each, and at intervals of about five minutes, the wind velocity averaged 110 miles per hour, and a few seconds in each period the average was approximately 120 miles per hour. Over a period of 15 minutes the average velocity was 100 miles per hour and over a period of 30 minutes the average velocity was 85 miles per hour. At 9:55 o'clock the velocity had fallen to 18 miles per hour and at 10 o'clock it was 11 miles per hour. A total of 0.36 inch of rain fell, 0.34 inch being concentrated between 9:15 and 9:39 p. m. (See fig. 1.)

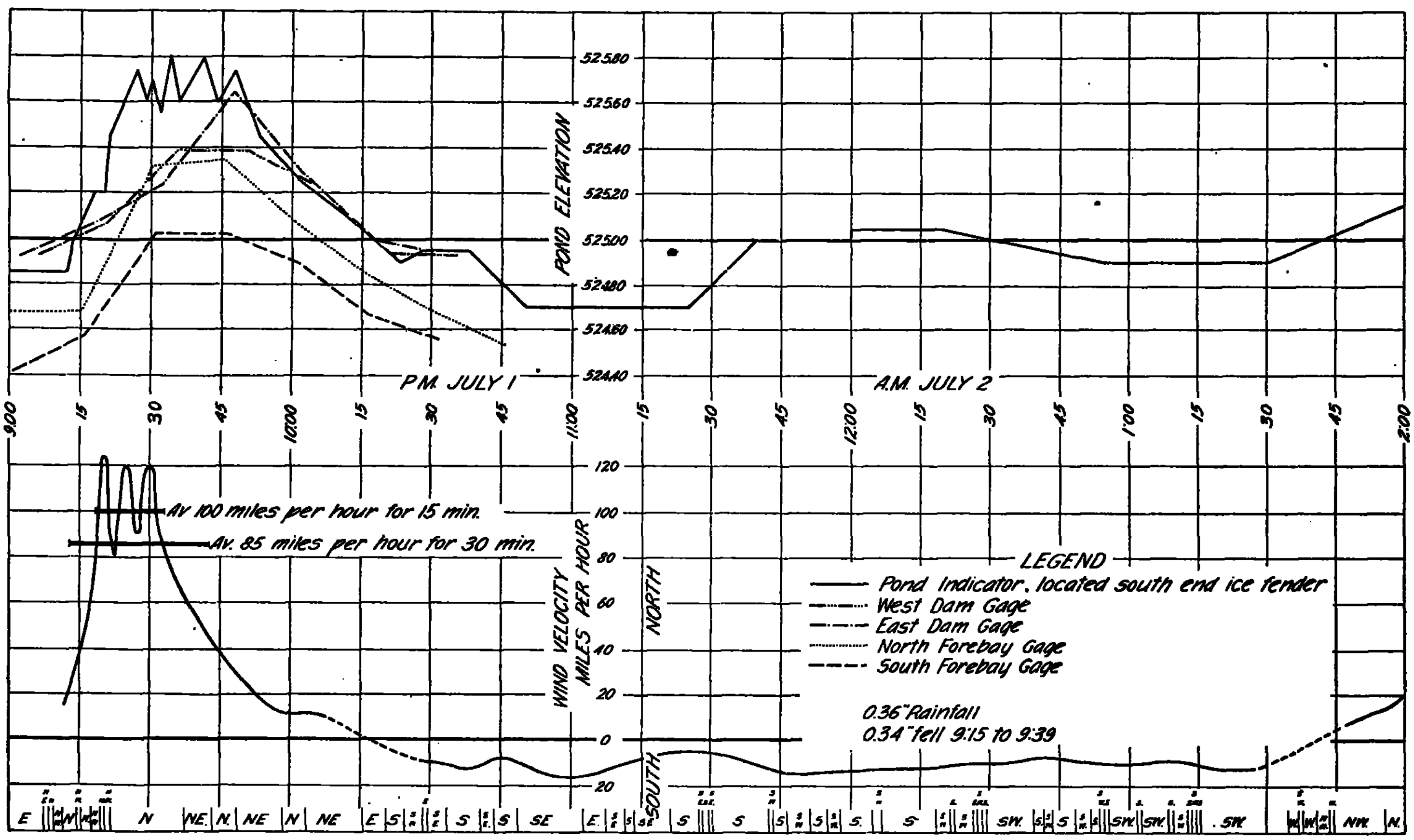

FIG. 1.

The storm was confined to a very small area. The wind which was generally easterly in direction before the storm, backed around into the north and northwest, striking in the vicinity of Montrose. It then followed down the river with its maximum intensity apparently at Keokuk. No traces of its effect were noticeable south of tower No. 12 on the transmission line, or 10 miles south of Hamilton, which is in direct line with the river from Montrose to Keokuk. No severe wind occurred at Fort Madison or outside of a few miles east and west of the main path of the storm. The local Weather Bureau official states that the storm was of the ordinary cyclonic type although its apparent drop from a high altitude to earth and back again was a characteristic of the tornado. Some have claimed that a funnel-shaped cloud accompanied the storm but this is very doubtful.

The Mississippi River Power Co. sustained no damages from the storm, but in the city of Keokuk a great deal of damage was done to trees and wires. Many streets were rendered impassable and trees up to 3 feet in diameter were blown over.

It would have been of interest to compare the wind velocity of this storm with that of the historic storms at Galveston and Houston. Mr. Daly states that at both of these places the anemometer blew off at 125 miles per hour. The anemometer of the power company is located at the top of the 60-foot flagstaff at the north end of the building and is 162 feet above the elevation of the lake or at elevation 687 feet M. D.

The effect of the wind on the various plant gages is not easy to understand. All of the plant gages are dampened down so that some have an opening from the gage well to the pond no larger than a lead pencil. This partly but not wholly explains the lag in effect on the gages after the wind began to blow. Note how closely the east and west dam gages follow the indicator on the falling side. It seems reasonable to believe that such a short sharp blow as occurred would not have been very uniformly distributed as to intensity over the area which it covered. Furthermore there would be a tendency toward higher water elevations in contracted places like the location of the ice fender indicator. Note also that all the gages, with the exception of the indicator, record only at 15-minute intervals and hence do not register changes in pond level as completely as the indicator. The change in pond elevation (rise) was 0.95 foot by the indicator and 0.72 foot by the east dam gage. If the high wind had continued longer both the east and west dam gages would probably have registered as high elevations as the indicator.

A series of surges occurred in the pond following the storm as shown by the indicator curve. These surges from crest to trough were of about one and one-fourth hours' interval. This would indicate that the surges went no farther upstream than Montrose, where the storm originated, for the time interval of wave movement between Fort Madison and the dam is two and one-half hours. The wave crest shown on the chart at 2 a. m. is the last one before the pond settled down to a constant elevation.

CORRELATION OF MAXIMUM RAIN INTENSITIES FOR LONG AND SHORT TIME-INTERVALS.

551.578.1

By ROBERT E. HORTON, Cons. Hydraulic Engineer.

[Voorheesville, N. Y., Oct. 20, 1920.]

Most studies of maximum rain intensities have covered intervals of two hours or less rain duration. Some attention has been given, as by the Miami Conservancy Commission, to maximum rain intensities having durations of one or more days. It is of interest, especially in attempting to discover the laws and physical processes governing high rain intensities, to compare the relation between intensity and duration for short intervals, as one hour or less, with similar relations for longer time-intervals, from one hour to one day, and for periods of one to five or six days covered by great storms.

Data showing maximum rain intensities from six recording rain gages at New Orleans, La., based on 25 years' records, afford a single example where a comparison of rain intensities for given time intervals from one minute up to one year may be made. The data are plotted on figure 1, the time being expressed in minutes by the horizontal scale, and the maximum amount of precipitation in the given time interval in inches is expressed by the ordinates. The observational data are indicated by small circles. These points apparently represent rain intensities having an average exceedance interval of about 25 years.

The term "exceedance interval" is used to define the average interval in years in which a given value of the magnitude of an event will be equaled or exceeded.

The equation

$$P_e=\frac{44tE-t^{0.222}}{60} \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ (1)$$

was worked out, using coefficients determined from the observational data for short durations. The values given by this equation are indicated on the diagram by triangles.

It will be seen that this simple expression represents with remarkable fidelity the observational data for time-intervals of 480 minutes, or eight hours, or less. This expression has, however, a maximum for $t=996$ minutes, which is readily obtained by differentiating equation (1). For time-intervals longer than this, it gives a smaller total precipitation than for time-intervals of less than 996 minutes. The maximum precipitation observed for longer time-intervals of course increases with the duration of the interval. This suggests that the curve representing the plotted points on figure 1 is really the combination of the graphs of two equations, one of which, namely that given, represents maximum rain intensities for relatively short intervals which are effected largely by local conditions, and second, normal precipitation unaffected by these special conditions. The latter is so small relative to the total amount for very short time-intervals that its omission from the left-hand portion of the curve on figure 1 is of little importance.

It is evident that if the time-interval was sufficiently long, say 50 to 100 years, then the maximum precipitation would approach closely as a limiting value, a quantity equal to kt, where k is the normal precipitation per unit of time (one minute in this case) as determined from the long-term mean rainfall at the given station. The long-term mean annual rainfall at New Orleans is 53.82 inches, which gives a value of $k=0.00010255$. The resulting limit line is designated B. It will be observed that the plotted points apparently approach this line as the duration increases.

The line C shows a continuation of the exponential function (1) beyond its maximum point. The value of this function becomes negligible for time-intervals exceeding 500,000 minutes. The portion of the curve DE represents the sum of the values of the curve C plus the values of some function which approaches the limit line B as the time-interval increases. Actually, the nature of this function is unknown, but it is probably some form of exhaustion equation, or exponential function, as is also the expression already given for the rainfall amount for time-intervals of one day or less.